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Nuclear Energy Reimagined: US Deployment of Integrated Energy Systems

Shannon M Bragg-Sitton

September 2019

The INL is a U.S. Department of Energy National Laboratory
operated by Battelle Energy Alliance

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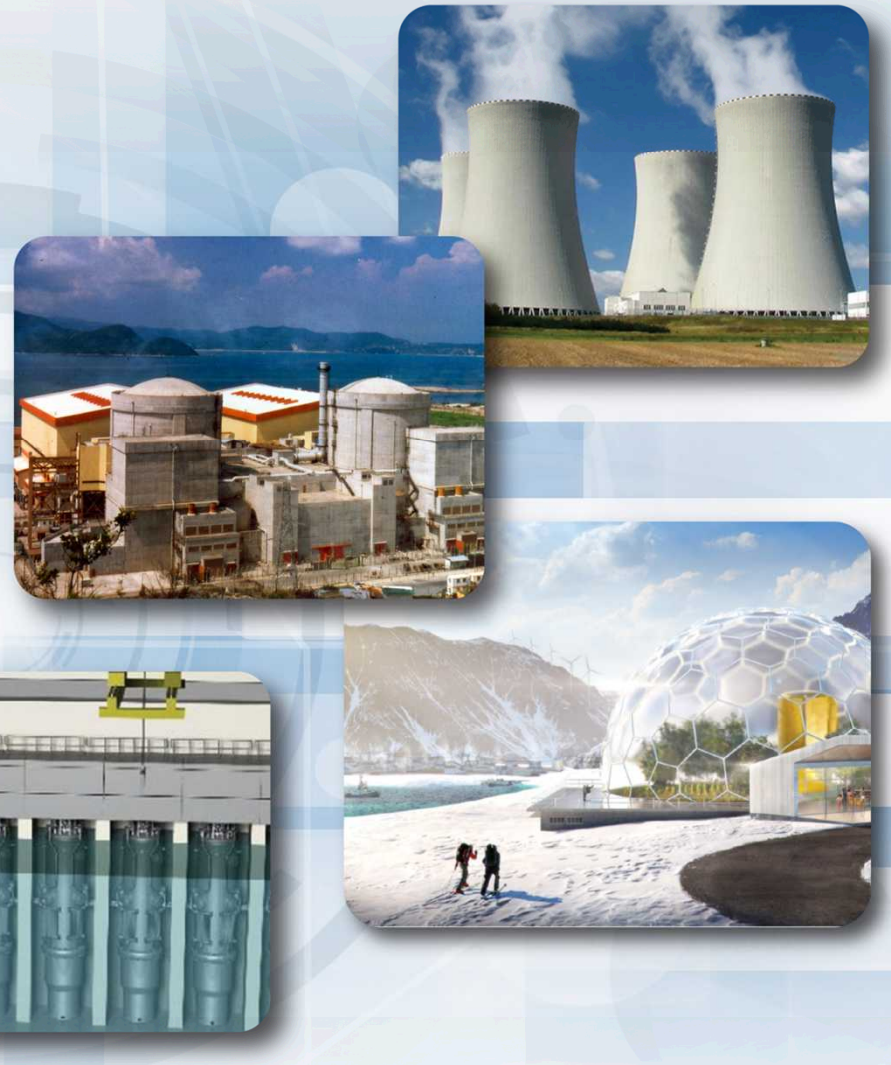
Nuclear Energy Reimagined: U.S. Development of Integrated Energy Systems



John Wagner, Ph.D.
Associate Laboratory Director
Nuclear Science & Technology

September 18, 2019

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Global Reality

28% by 2040

Projected increase in world energy use by U.S. Energy Information Administration.*

2.7 degrees by 2040

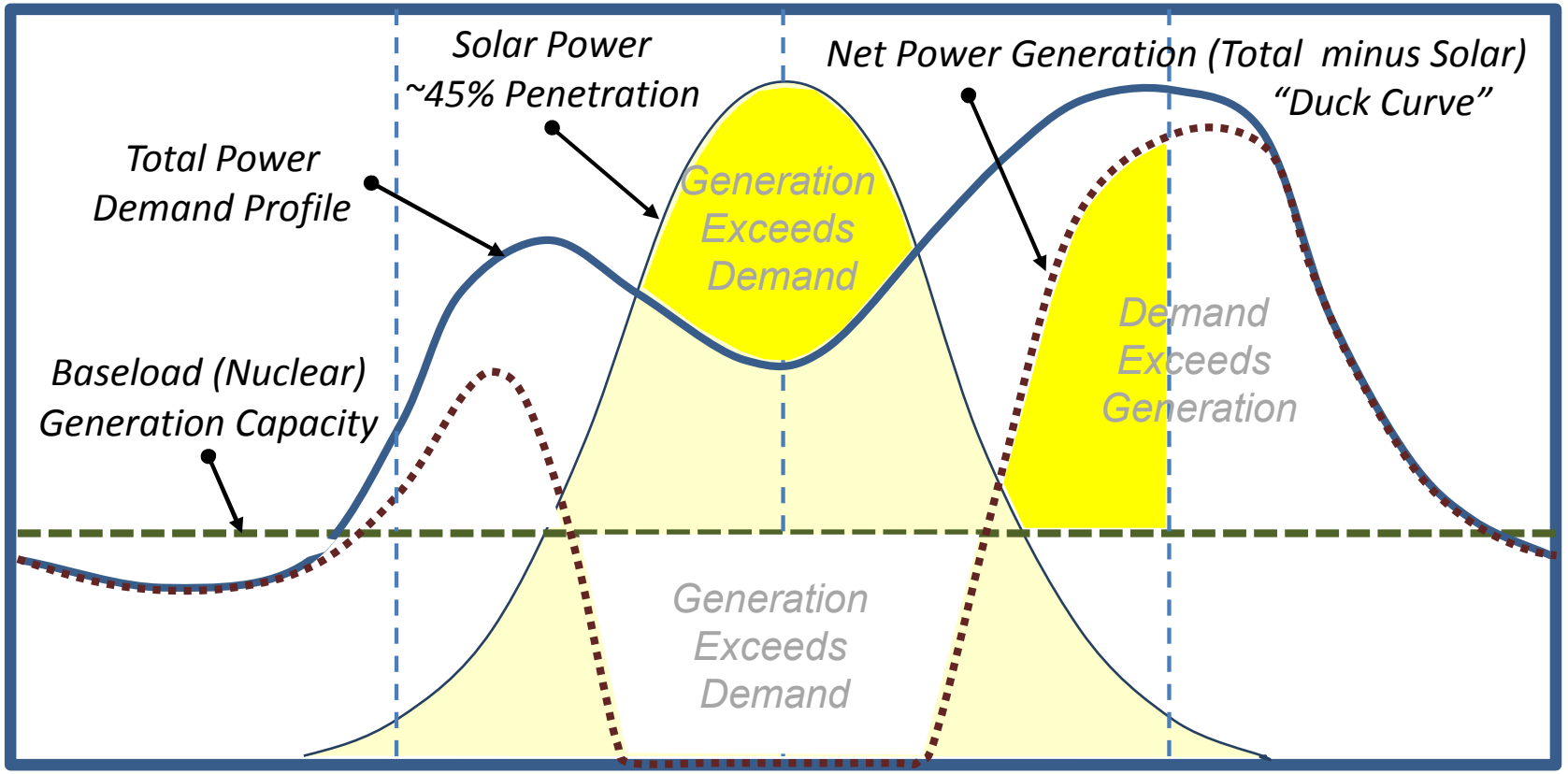
Projected increase in atmospheric temperatures if global greenhouse gas emission continue at current rate by Intergovernmental Panel on Climate Change

Nuclear Power Can Save the World
Expanding the technology is the fastest way to slash greenhouse gas emissions and decarbonize the economy.
By Joshua S. Goldstein, Staffan A. Qvist and Steven Pinker
https://www.nytimes.com/2019/04/06/opinion/sunday/climate-change-nuclear-power.html

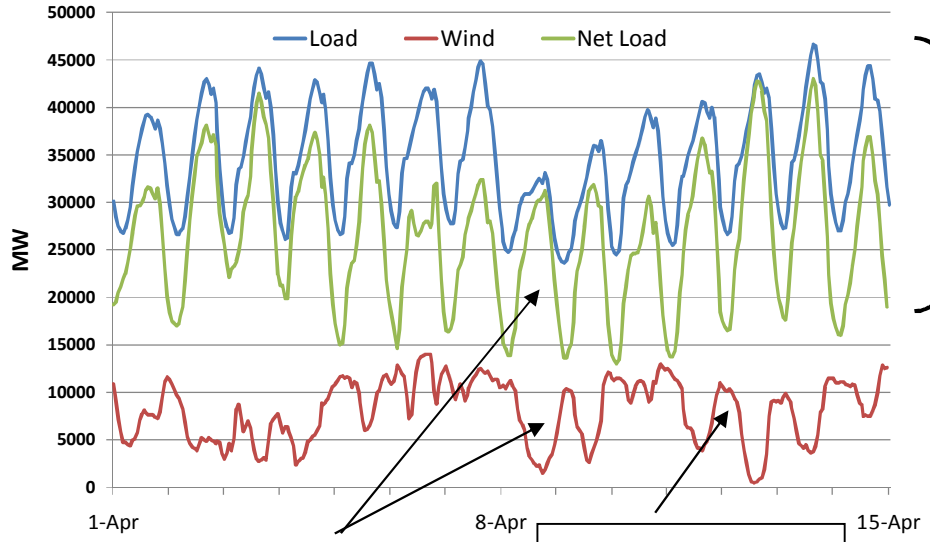
The Next Generation of Federal Clean Electricity Tax Credits
Federal policy makers should design a new generation of tax incentives… to decarbonize the US electricity sector almost entirely by midcentury—an integral step in decarbonizing the overall economy to combat climate change.
By Dr. Varun Sivaram and Dr. Noah Kaufman
https://energypolicy.columbia.edu/research/commentary/next-generation-federal-clean-electricity-tax-credits

A major US utility is moving toward 100% clean energy faster than expected
Xcel Energy…committed to going completely carbon-free by 2050…carbon-free includes not only renewables but also advanced nuclear power plants and fossil fuel power plants with carbon capture and sequestration…
By David Roberts, Vox
https://www.vox.com/energy-and-environment/2018/12/5/18126920/xcel-energy-100-percent-clean-carbon-free

Solar Challenges to Baseload Nuclear Power Plants

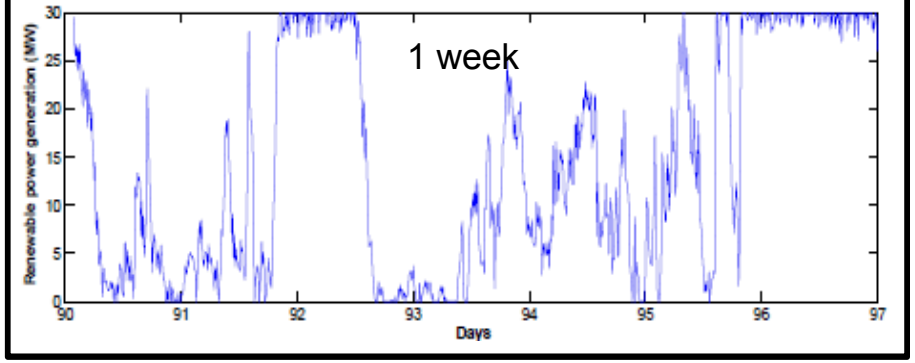


Wind Challenges to Baseload Nuclear Power Plants



Ramp Range (Increases in this two-week period from 19.3 GW/day to 26.2 GW/day)

Wind Generation Profile in Wyoming



Variation in wind output increases net load ramp rate (Increases in this period from 4,052 MW/hour to 4,560 MW/hour)

Uncertainty in wind output increases uncertainty in net load to be met with conventional generators

Western Wind and Solar Integration Study, Phase II, (2013)

1) Increased need for frequency regulation
2) Increase in hourly ramp rate
3) Increase in uncertainty of net load
4) Increase in ramp range

Energy Reimagined

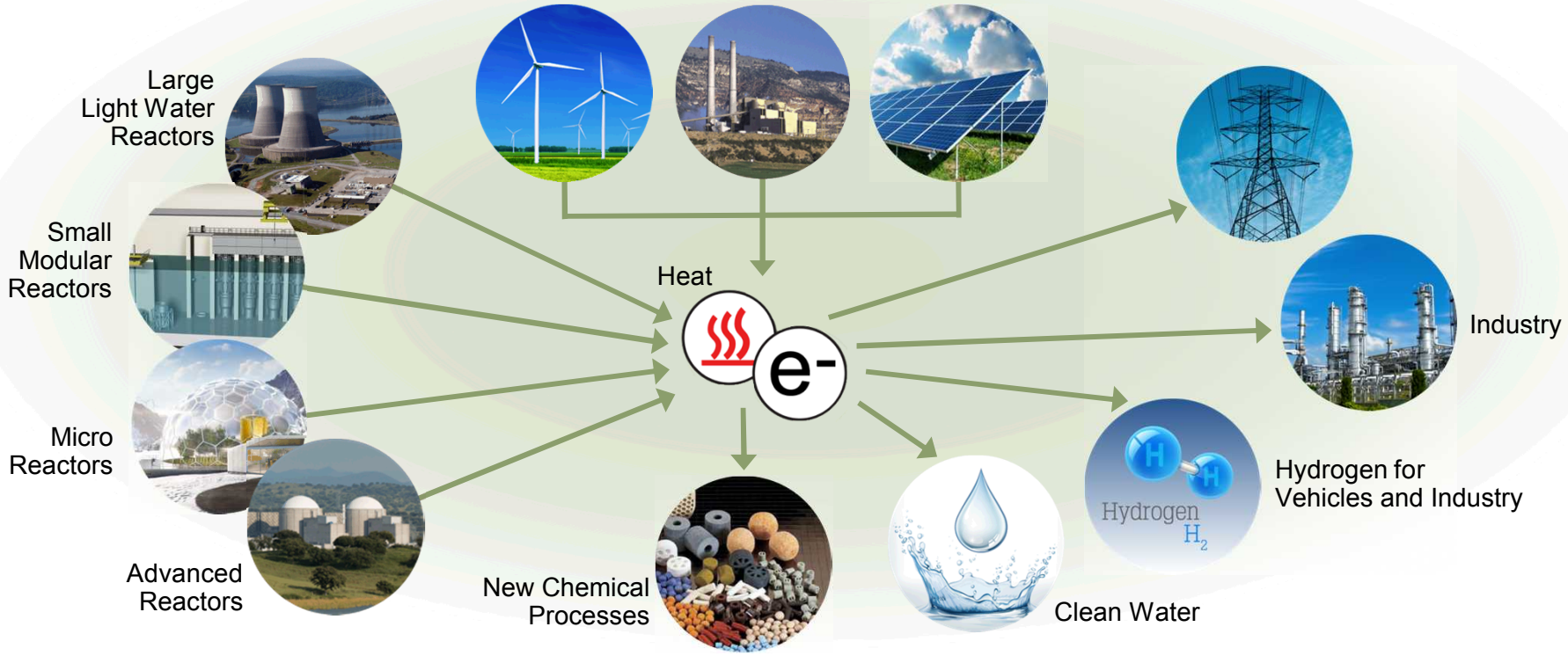
Maximizing energy utilization, generator profitability, and grid reliability and resilience through novel systems integration and process design

Today

Electricity-only focus

Potential Future Energy System

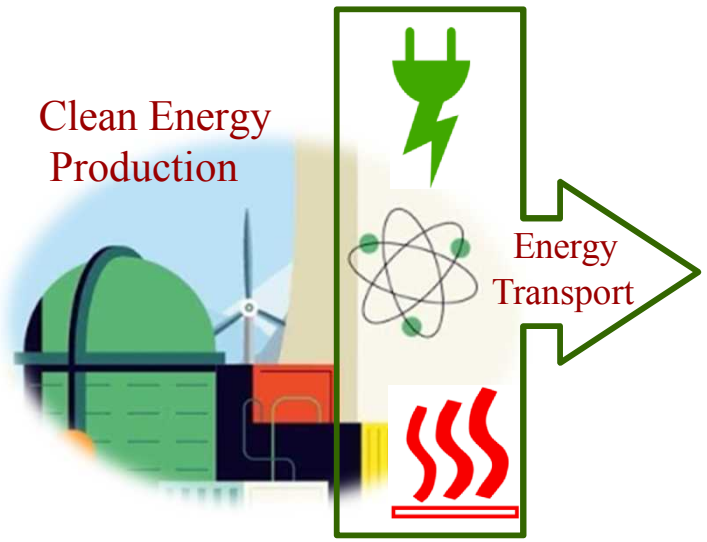
Integrated grid system that leverages contributions from nuclear fission beyond electricity sector



Flexible Generators ❖ Advanced Processes ❖ Revolutionary Design

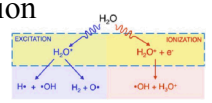
A new paradigm for nuclear energy

1) Direct tie to plant substation for electricity dispatch
2) Tie in independent steam loop for thermal duties
3) Produce energy carriers such as hydrogen and other chemical feedstock



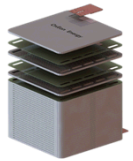
Process Electrification

- Water Electrolysis (AE and PEM)
- Desalination with RO
- Non-thermal plasmas excitation



Process Intensification

- Steam Electrolysis / Co-Electrolysis (HTSE)
- Advanced catalysis
- Electro/thermal conversion applications



Evolutionary Direct Conversion

- Proton-conducting ceramics
- Multi-functional micro chemical reactors
- Proton initiating CO_2 reduction
- Nitrogen fixation

Fresh Water
Hydrogen
Reformate

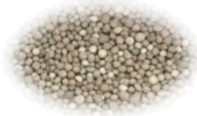
Syngas & Hydrogen Chemical Feedstock

Polymers & Mixed Alcohols

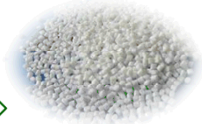
Water

Lubricants

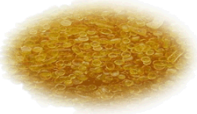
Fuels



Fertilizers



Polymers

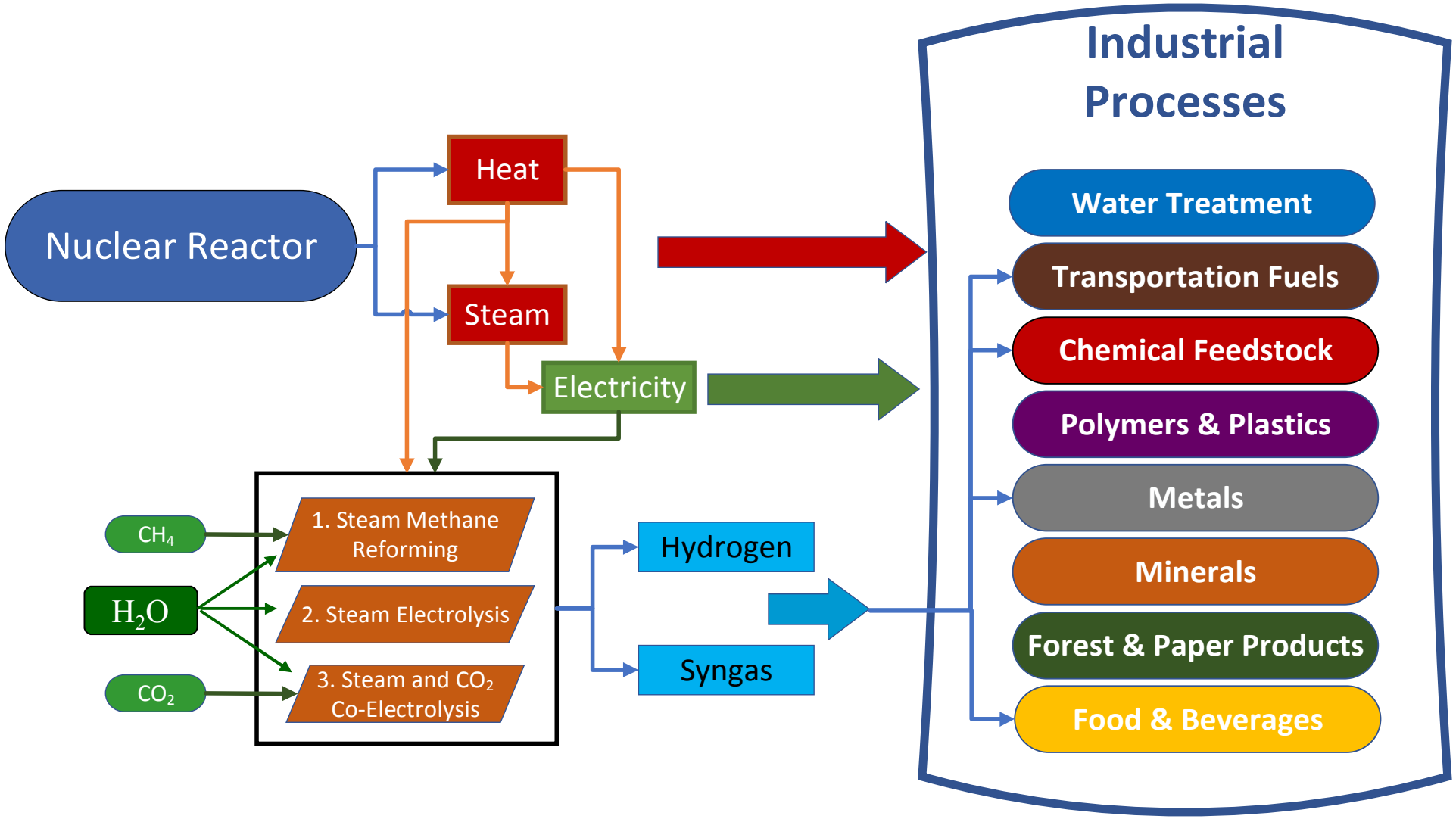


Specialty Chemicals

Flexible Nuclear-Industrial System

*May be loosely coupled with **renewable generators** in the regional grid balancing area that cause increased variation in net demand.

Begin by moving energy from LWRs to industry using energy carriers like hydrogen



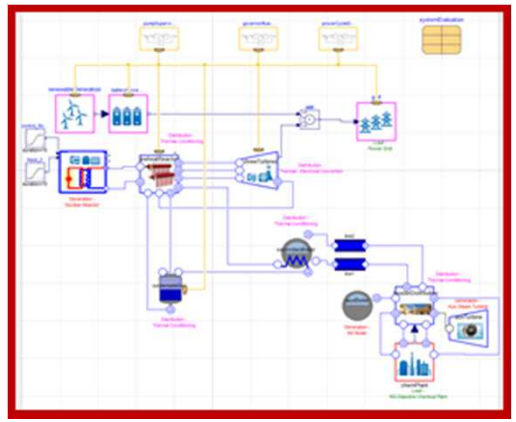
Technical & Economic Assessments (TEA)

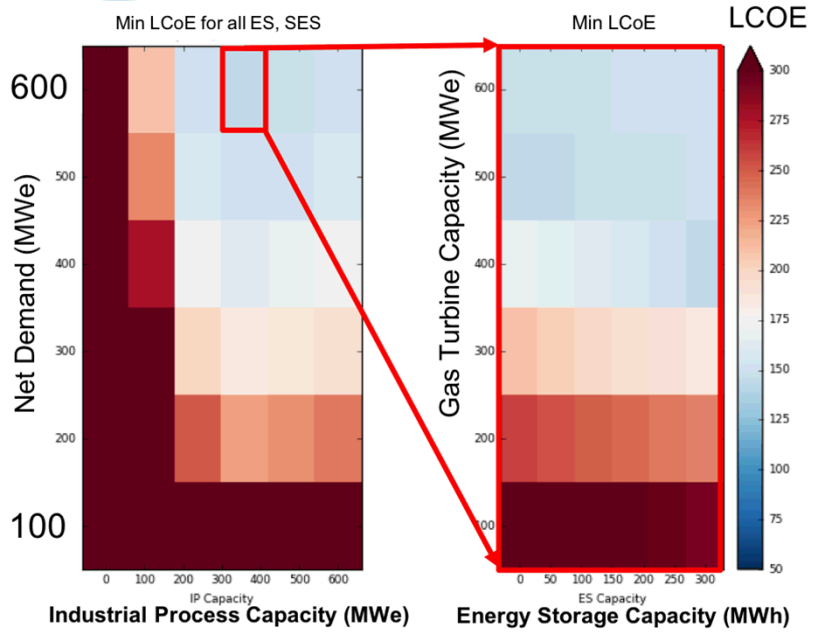
Resource Potential
- Market size
- Resource availability
- Resource attributes
- Infrastructure requirements

Technology Potential
- Thermodynamics
- Performance
- Systems integration and control

Economic Potential
- Projected costs
- Return on investment

Market Potential
- Competition
- Policy, Regs





*Priority Application: Conceptual H_2@Scale Energy System**

Can hydrogen effectively be a new energy currency for LWRs?

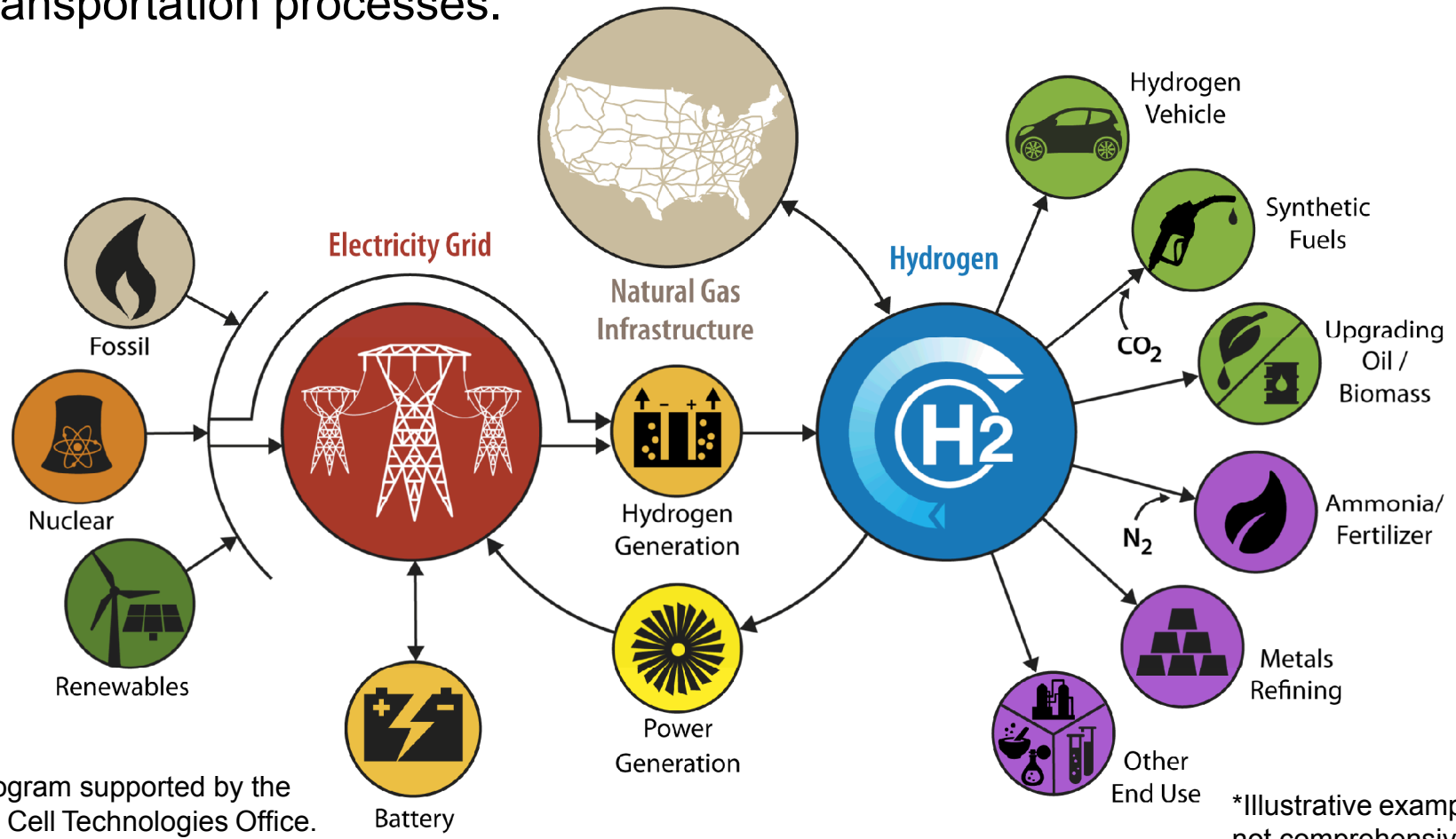
Vision: Leverage hydrogen's unique ability to address cross-energy sector issues and to enable clean, efficient industrial and transportation processes.

Hydrogen Attributes:

- Clean and convenient energy carrier
- Scalable energy storage
- Vital to fuels and chemicals production
- Used to upgrade coal to higher value products

Other key H2@Scale Benefits:

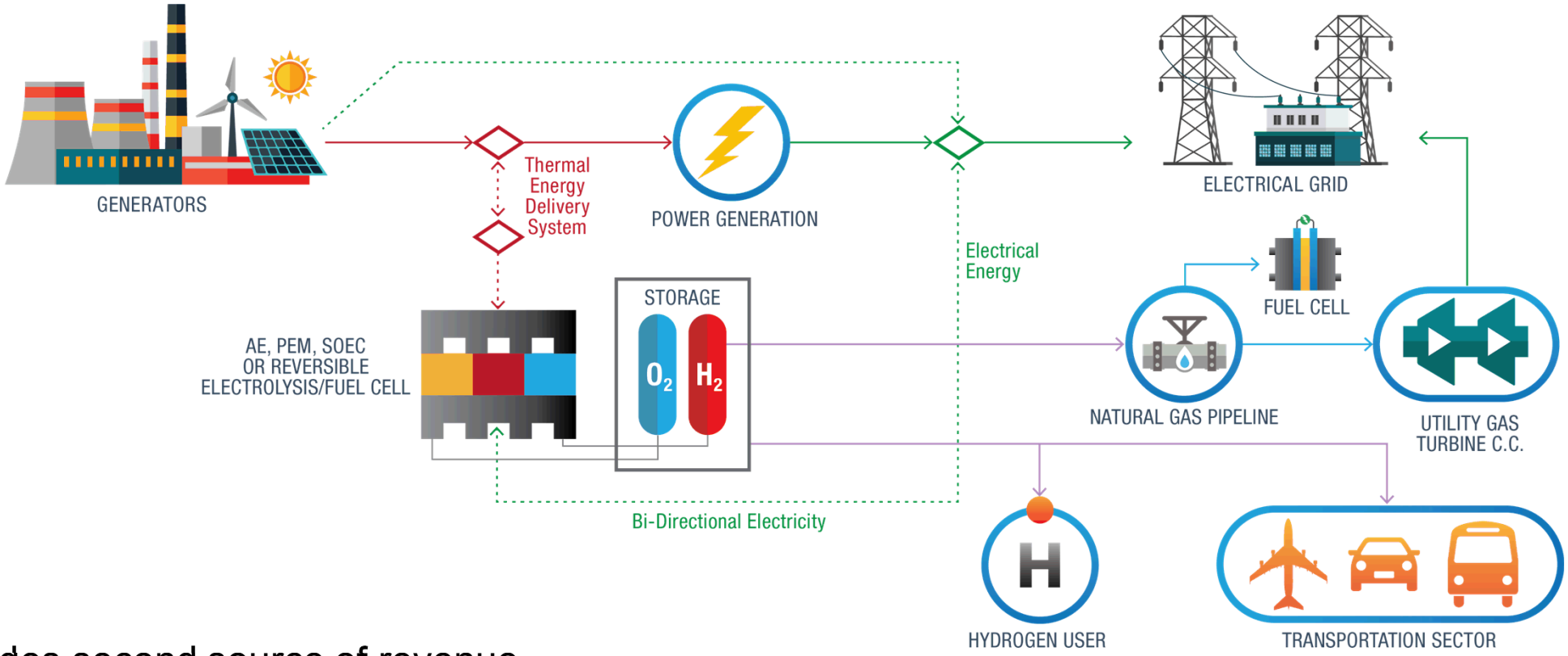
- Provides grid resiliency
- Deeply reduces air pollutant emissions



**H2@Scale is a complementary, collaborating program supported by the DOE Energy Efficiency & Renewable Energy Fuel Cell Technologies Office.

*Illustrative example, not comprehensive

Example LWR Hybrid: Hydrogen Production via Steam Electrolysis



1) Provides second source of revenue
2) Provides energy storage, for electricity production or hydrogen user
3) Provides opportunity for grid services; reserves and grid regulation

Maximum growth potential of hydrogen market by 2050 is 16X.

- Chemicals and fuels synthesis
- Steel manufacturing
- Ammonia-based fertilizers

Recently Completed Analyses for Current Fleet LWRs

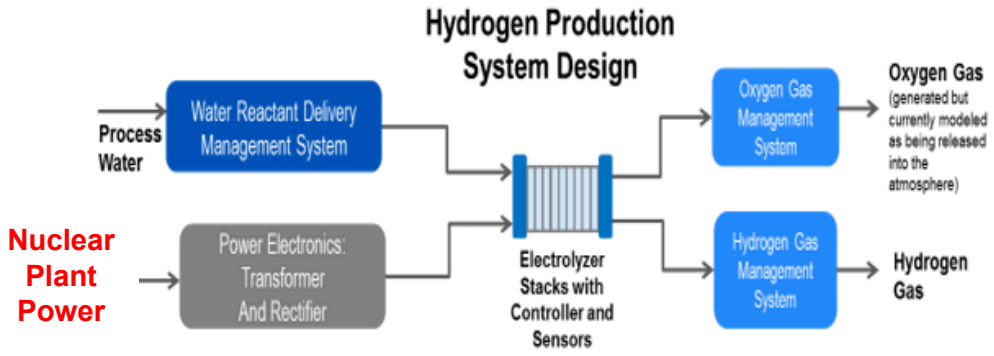
INL issued public-facing reports on three key studies in FY19 that provide the foundation for demonstration of using LWRs to produce non-electric products:

- *Evaluation of Hydrogen Production Feasibility for a Light Water Reactor in the Midwest*
  - Technical and economic potential for repurposing of an existing Exelon plant for H2 production; analyses included use of the produced hydrogen for multiple off-take industries (ammonia and fertilizer production, steel manufacturing, and fuel cells)
- *Case Study: Integrated Nuclear-Driven Water Desalination – Providing Regional Potable Water in Arizona*
  - Economic viability of coupling a reverse osmosis (RO) water desalination facility with an LWR, focusing on the Palo Verde Generating Station and conducted in collaboration with Arizona Public Service
- *Evaluation of Non-electric Market Options for a Light-water Reactor in the Midwest*
  - Evaluation of market opportunities for LWRs with a focus on hydrogen production using low-temperature and high-temperature electrolysis, with an initial look at producing polymers, chemicals, and synfuels

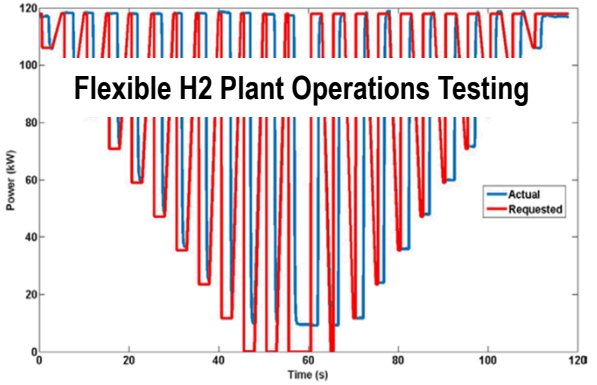
Demonstrations Projects: INL Partners with Utilities to Produce H2

- ***DOE H2@Scale Funding Opportunity***
- Joint DOE Nuclear Energy and Fuel Cell Technology Office project to demonstrate hydrogen production with power from a commercial nuclear power plant
- **Exelon Corporation – Lead Utility**
  - $3.6 million DOE (Cost-share NE & EERE)
  - $3.6 million Exelon Corporation
  - Install and Test 1-2 MW_e electrolysis at a LWR nuclear plant in the U.S. Midwest
- Hydrogen to be supplied to industries with interest in clean, carbon-free feedstock

- ***DOE NE Industry Opportunities for Advanced Nuclear Technology Development***
- Accelerating Advanced Nuclear in the U.S.
- Project to evaluate technical and economic feasibility of large-scale hydrogen production
- Demonstration of integrated energy systems that enable nuclear energy to be used to produce non-electrical products (e.g. hydrogen)
- **FirstEnergy, Xcel Energy, Arizona Public Services**
  - $9.1 million DOE (Cost-share NE)
  - $2.3 million Utility Partner Cost-Share



Nuclear Plant in Midwest



What might the future entail for nuclear?

Image courtesy of GAIN and ThirdWay, inspired by *Nuclear Energy Reimagined* concept led by INL.

Download this and other energy park concept images at:
https://www.flickr.com/photos/thirdwaythinktank/sets/72157665372889289/

https://inlcareers.inl.gov/

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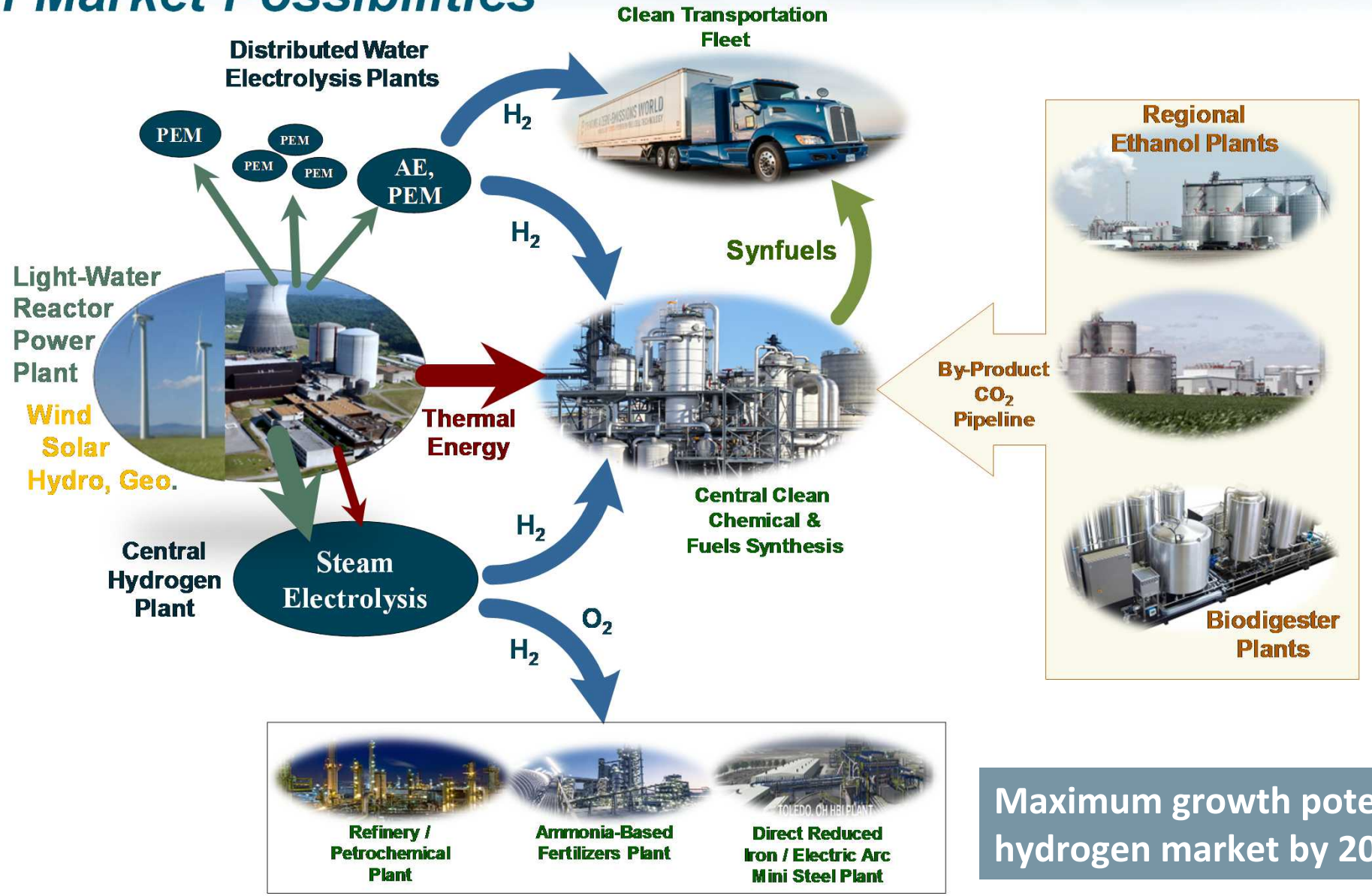
Hydrogen Market Possibilities

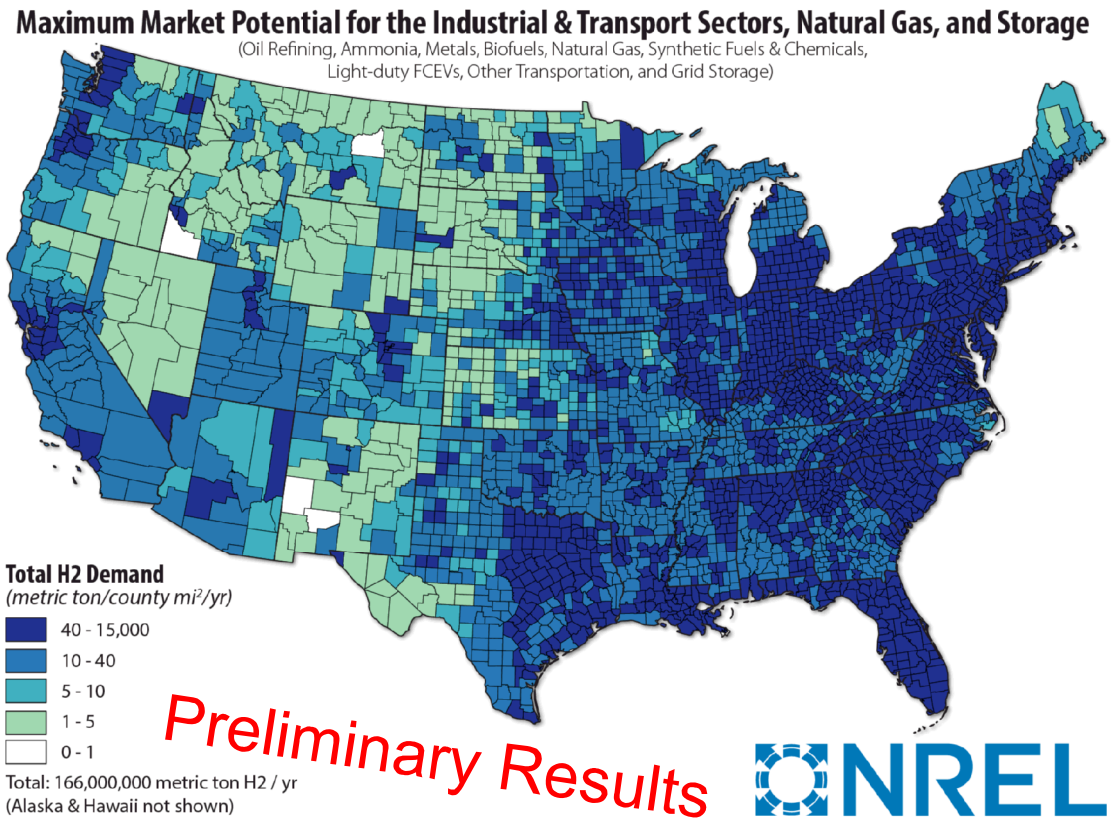


Maximum growth potential of hydrogen market by 2050 is 16X.

Maximum H2 Market Potential in the U.S.

Application	Maximum Market Potential (MMT/yr)
Refineries and the chemical processing industry (CPI) [a]	8
Metals	12
Ammonia	4
Biofuels	4
Synthetic fuels and chemicals	14
Natural gas supplementation	10
Light-duty fuel cell electric vehicles (FCEVs)	57
Other transportation (Medium- & Heavy-Duty)	29
Seasonal energy storage for the electricity grid	28
Total	166

Maximum growth potential of hydrogen market by 2050 is 16X.



Definition: The maximum market potential is the estimated market size constrained by the services for which society currently uses energy, real-world geography, and system performance, but not by economics.

1. Resource quantities based on Connelly, et al (2018) "Resource Assessment for Hydrogen Production"